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Alterations of summer ice conditions within eastern part of the Northern Sea Throughway

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Abstract. The article is considered methodology and results of computer processing of vector ice maps of the AARI archive for the period 1997-2018. The charts were produced by processing of Earth's remote sensing data. There were analyzed inter-annual variability of navigation conditions along two routes between the Sabetta Port (the Yamal Peninsula, Russia) and the Bering Strait during September that is annual period of the most light ice conditions. As the results of the processing there were obtained long-standing series of total lengths of the routes legs within free water, within close floating ice with concentration more than six tenths, and such integrated ice index as conditional lengths of the routes within compact floating ice with 10 tenths concentration. The series belong ten-days periods (decades) during September. The series were tested for the existence of trends by the method of integral curves, and then were examined for heterogeneity using Wilcoxon-Mann-Whitney and Siegel-Tukey rank non-parametric criteria. We received the following results: the total lengths of the routes legs within free water increased for the period of 1997-2018 years, ones within close floating ice and conditional lengths of the routes within compact floating ice decreased. There is some improvement of the ice conditions.

1. Introduction

Effectual economy management in the Russian Arctic demands exploitation of the Northern Sea Throughway that is the system of routes along the Northern Eurasian coast [1, 2, 3, and 4]. There is expectation of the Northern Sea Throughway cargo traffic increase in nearest future due to year-round hydrocarbons traffic from coast pipeline terminals and marine oil and natural gas production platforms. The natural gas liquefaction plant in the Sabetta City (the Yamal Peninsula, Russia) is one of the largest ones in the world, and the liquefied gas producing is increasing. Marine transport operations in the Arctic Ocean are necessary for: 1) Hydrocarbons (oil and liquid gas) shipment, 2) Freightage of ore mineral resources and metals, which are products of the ore resources processing. The metals are nickel, copper, palladium, platinum, produced by Public Joint Stock Company “Mining and Metallurgical Company “NORILSK NICKEL” and others, 3) Russian northern regions supply by provisions and consumer goods, 4) Support of Russia defence capability including supply of the military bases, infrastructure of State Border of the Russian Federation, and the Russian naval fleet, 5) Carrying out of tourist voyages. There is an imperative need to provide hydrocarbons marine transportation from oil and gas fields within Northern Russia and Russian Arctic Seas up to Europe, Japan, China, Korea, and other countries of Eastern Asia by forecasts of ice conditions along the



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Northern Sea Throughway. The global climate warming can lead to significant improvement of ice conditions along the Throughway. Long since there were wishes about easy navigation along northern coast of Eurasia, at least during summer. In the 1980s, the Arctic ice cover was mainly strong thick pack. Then the ice has transformed to more fragile, younger, and thinner ice. In the summer, it is more vulnerable to melting out. The change promotes lower minimum ice extents [5, 6, and 7]. The global warming can be a consequence of human activity [8]. There is an opinion that the Arctic warming will lead to significant improving of the ice navigation conditions [9].

Ambitious integrated project YAMAL LNG (liquefied natural gas) encompasses production of natural gas, its liquefaction and shipment. The project is realized on the Yamal Peninsula, and uses the South Tambey Field resources [10]. Liquefied-gas vessels of “Christophe de Margerie” type accomplish the shipping without icebreaker support. The type has high ice class of “Arc7”. At present, the shipping is carried out by six vessels of the type. There is intention to use for the shipping 15 vessels of the type. Our research goal consists in examination of 22-year variability of ice navigation conditions along marine routes from the port of Sabetta up to the Bering Strait with possible revealing of significant alterations.

2. Materials and methods

Ice charts of the AARI archive correspond some temporal intervals of satellite Earth remote sensing and water area of definite sea. We consider ice data corresponded ten-day intervals for September. However for some ten-day periods we have two sets ice charts, but for others only one set of the charts. If there are two ice charts for a ten-day period and the same sea, in this case we have to use average values of the ice cover parameters according to the charts. The first stage of the ice charts processing consists in the ice charts automated processing by means of ArcGIS. The processing includes usage of set of specially designed programs in the Python. The Python’s programs are used in ArcGIS map documents for renaming of the original charts shapefiles, cartographic projection conversion of the shapefiles, merge of the shapefiles with ice data for different seas and the same temporal interval, overlay operations of intersection between navigation routes and the layers of ice information. Results of the intersections are polyline objects with semantic ice characteristics. We examined in the research two sea routes from Sabetta Port to the Bering Strait: the northern one and route for the liquefied-gas vessels navigation. The northern route is shorter (2350 nautical miles) than the liquefied-gas vessels one (2428 n.m.). The liquefied-gas vessels route is situated with taking into account permissible depth for navigation of the “Christophe de Margerie” type vessels. The routes are demonstrated in the figure 1.

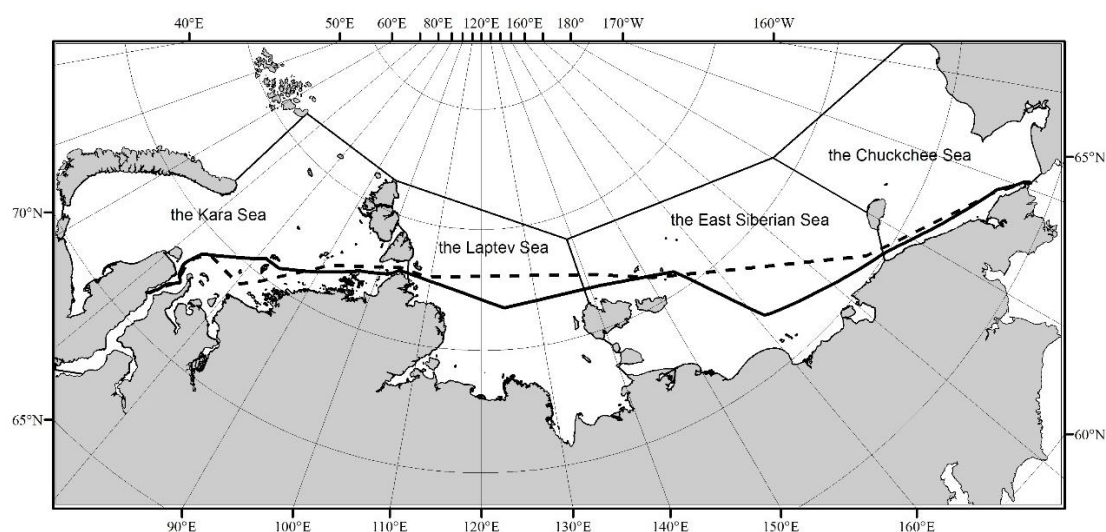


Figure 1. Routes: northern (---) and liquefied-gas vessels (—).

In addition, we separately examined sections of the routes within the different seas. For each leg of the routes are calculated the conditional length of compact floating ice with 10 tenths concentration. The conditional length means result of multiplication of the leg total ice concentration in fractions of one at the leg length. For example, total ice concentration of a route leg equals to one tenth, and the leg length equals to 100 nautical miles. Therefore, the conditional length of compact floating ice within the leg equals to 10 n.m.

Then the Python's programs are used for semantic queries making with generation of new shapefiles. The queries select the spatial objects according to total ice concentration of the routes legs. Consequently, there are generated polyline layers with objects only within free water and with objects within close floating ice with ice concentration more than six tenths. Then the Python's programs generated new shapefiles with single spatial object. The attribute tables of the shapefiles contain values of summarized conditional length of a route, total length of legs of a route within free water and objects within close floating ice. However, there are ten-day periods with two ice charts for two different temporal intervals within the periods. In these cases, specially designed Python program calculates average values of the ice parameters, which correspond to the ten-day periods in whole, and generates new shapefile with the average value as the shapefile semantic characteristic. At the next stage of the processing, the Python's programs merge all shapefiles corresponding different years, but the same ten-day interval within September. Thus, for example, all shapefiles with total values of a route length within free water are merged in new shapefile. Attribute tables of the new shapefiles are used at the next stage of the processing.

Here we use designed application workspace of Mathcad to plot graphs of cumulative curves. Along the X-dimension of such graph there is set the sequence of the year number. Inside the chart field there is set cumulative values of some results of the processing. For example, let us consider cumulative curve of inter-annual dynamics of total length of a navigation route within free water at certain ten-day period of September. The program puts in the graph opposite the tick of the first considered year a point with ordinate value equal to the parameter value of the first year itself. At the second year, the program puts a point with ordinate value equal to sum of the values for the first and second years, at the third year – sum of the values for the first, second, and third years and so on. Thus, the program puts in the graph opposite a year tick a point with ordinate value equal to sum of all values of the parameter from the first year up to this year. The program connects all the graph point in a line. If the line looks like a straight line, it means that all the values of the parameter possibly belong the same general totality. If the line looks like a curve, and has fracture (bend) or few fractures, it can mean that not all the values of the parameter belong to the same totality. In the case of straight line, the numerical series of the parameter values must be divided in twain. Otherwise, in the case of the curve with fracture or bend the initial sequence of the parameter values must be separated at place of the fracture or bend. Then we have to test the null-hypothesis that two new numerical series, which are results of the initial sequence separation, belong to the same totality. We do it by usage of two designed programs of Mathcad, which test the null-hypothesis by the non-parametric criteria of Wilcoxon-Mann-Whitney and Siegel-Tukey.

3. Results

The research reveals inhomogeneity of all numerical series of the above-mentioned integrated parameters of ice navigation conditions for the routes “Sabetta Port – Vilkitski Strait – Bering Strait” and sections of the routes within the different seas. Majority of fractures or bends on the cumulative curves is situated opposite ticks of 2004-2005 years. It is evident significant improvement of September ice navigation conditions along the routes during period of 1997-2018 years. The investigation shows for the all routes increase of total length of the route legs within free water, decrease of total length of the route legs within close floating ice with ice concentration more than six tenths, and decrease of conditional length of compact floating ice. Comparison between average values of the above mentioned integrated parameters of ice navigation conditions within the northern route and the liquefied-gas vessels one for two parts of period of 1997-2018 years is presented in the

table 1. The table shows that the liquefied-gas vessels route has better navigation conditions. The “relative length” term in the table and in other tables and figures means the quotient of division of some integrated length value for a route (for example, total length of route legs within free water) per total length of the route. Improvements of the navigation conditions are practically the same for the northern route and the liquefied-gas vessels route. Thus, average September increase of the relative length within free water for the northern route equals to 24.0%, and for the liquefied-gas vessels route – 23.3%. The corresponding decreases of the relative lengths within close floating ice with ice concentration more than six tenths equal to 19.0% and 16.7%, decreases of the relative conditional lengths of compact floating ice amount to 19.7% and 18.0%.

Table 1. Average relative lengths with mean square deviations (%)

Month, ten-day interval	The northern route		The liquefied-gas vessels route	
	1997-2007	2008-2018	1997-2007	2008-2018
Relative length of the routes within free water				
9_1	68 ± 21	87 ± 7	72 ± 21	92 ± 5
9_2	67 ± 24	92 ± 6	72 ± 22	96 ± 5
9_3	62 ± 25	90 ± 8	68 ± 26	94 ± 7
Relative lengths of the routes within close floating ice				
9_1	19 ± 19	6 ± 6	15 ± 18	2 ± 3
9_2	23 ± 20	4 ± 5	15 ± 15	1 ± 2
9_3	33 ± 21	8 ± 7	26 ± 20	3 ± 5
Relative conditional lengths of compact floating ice				
9_1	22 ± 18	7 ± 5	17 ± 17	4 ± 3
9_2	24 ± 19	5 ± 5	18 ± 16	2 ± 3
9_3	33 ± 22	8 ± 7	28 ± 21	3 ± 5

Comparison between average relative lengths of the routes within close floating ice with ice concentration more than six tenths in second ten-day interval of September in the first and second parts of the period of 1997-2018 years is presented in the figure 2.

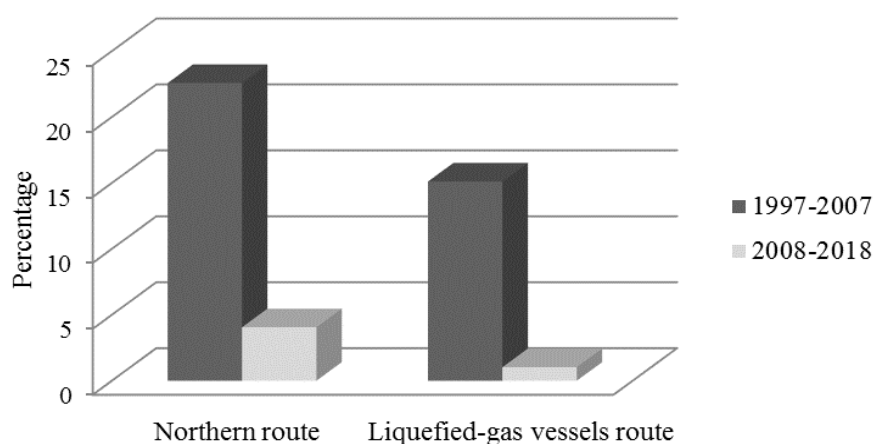


Figure 2. Average relative lengths of the routes within close floating ice in second ten-day interval of September

Comparison between average relative conditional lengths of compact floating ice of the routes in first ten-day interval of September in the first and second parts of the period of 1997-2018 years is presented in the figure 3.

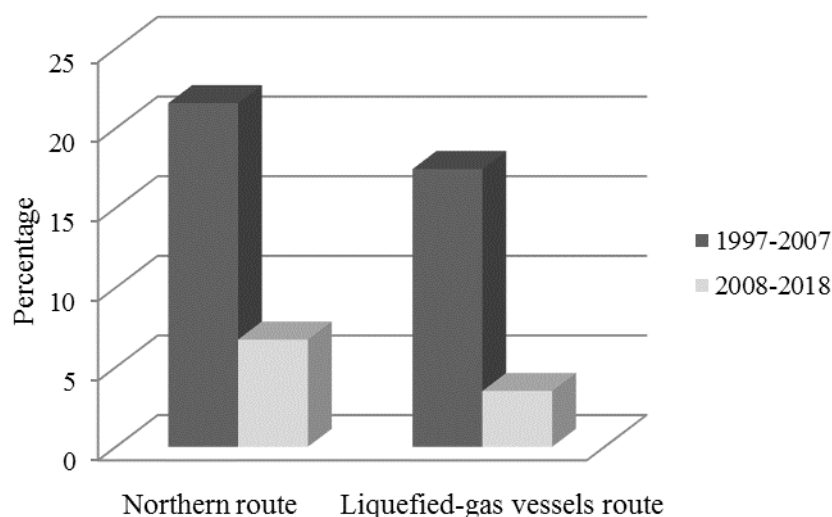


Figure 3. Average relative conditional lengths of compact floating ice in first ten-day interval of September

The figures 2 and 3 demonstrate considerable reduction of the parts legs with severe ice conditions. In the figure 4 we can see average relative lengths of the routes within free water in first ten-day interval of September. The figure shows the same scale of alterations, as the figures 2 and 3.

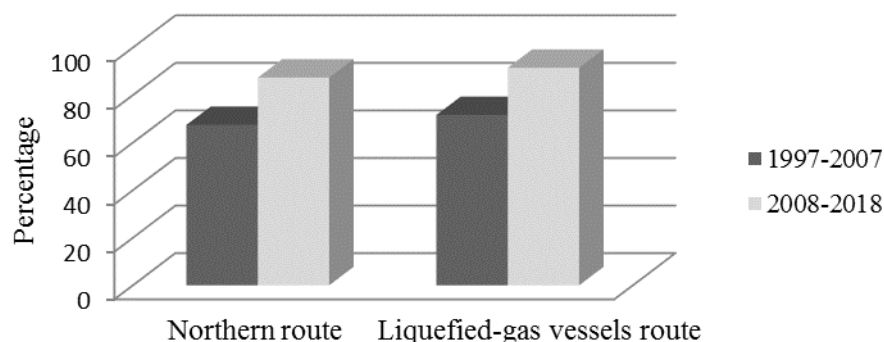


Figure 4. Average relative lengths of the routes within free water in first ten-day interval of September

The figures 5 and 6 present temporal regression relationships of relative length of the liquefied-gas vessels route within free water and relative length of the route within close floating ice in third ten-day interval of September. These graphs confirm existence of directional trends in alterations of the ice navigation conditions within the eastern part of the Northern Sea Throughway (the routes “Sabetta Port – Vilkitski Strait – Bering Strait”). Specific features of the ice parameters alternations in September during the period of 1997-2018 years for sections of the routes within the Chukchee Sea, the East Siberian Sea, the Laptev Sea, and the Kara Sea are presented in the table 2. This table shows that the best navigation conditions are noticed within the Chukchee Sea.

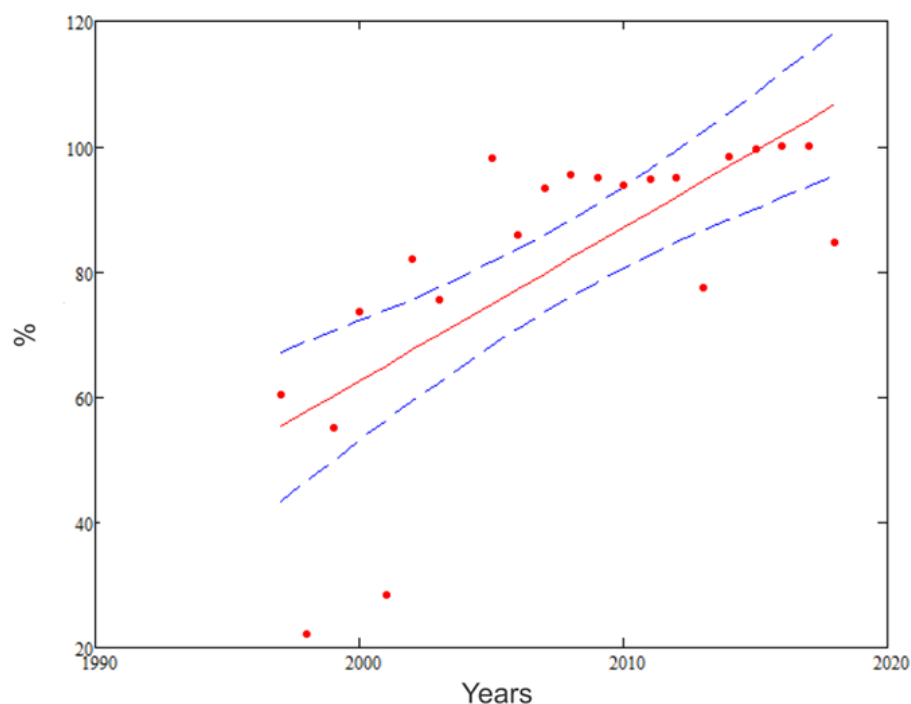


Figure 5. Temporal regression relationship of relative length of the liquefied-gas vessels route within free water in third ten-day interval of September

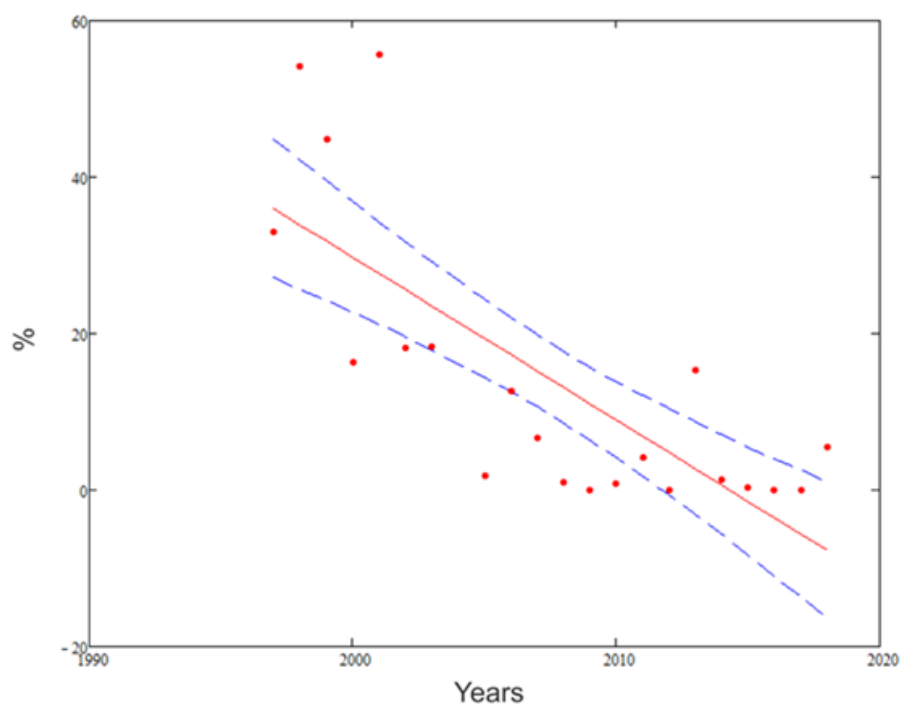


Figure 6. Temporal regression relationship of relative length of the liquefied-gas vessels route within close floating ice with ice concentration more than six tenths in third ten-day interval of September

Table 2. Average relative lengths for September (%)

Sea	The northern route			The liquefied-gas vessels route		
	1997-2007	2008-2018	alteration	1997-2007	2008-2018	alteration
Relative length within free water						
Kara	78.5	95.4	+16.8	79.6	96.1	+16.5
Laptev	48.8	88.1	+39.2	61.2	95.8	+34.7
East Siberian	51.8	80.8	+29.0	60.4	87.7	+27.3
Chukchee	84.9	99.0	+14.1	83.7	99.0	+15.3
Relative lengths within close floating ice						
Kara	13.9	2.1	-11.8	12.5	1.7	-10.8
Laptev	40.3	8.4	-31.9	28.1	0.8	-27.2
East Siberian	34.8	10.5	-24.3	23.4	3.9	-19.5
Chukchee	9.7	0.0	-9.7	9.2	0.0	-9.2
Relative conditional lengths of compact floating ice						
Kara	15.2	2.5	-12.7	14.0	2.1	-11.9
Laptev	40.5	9.3	-31.2	29.3	1.7	-27.7
East Siberian	37.0	11.8	-25.2	27.5	5.8	-21.7
Chukchee	10.8	0.3	-10.5	11.1	0.2	-10.9

4. Discussion and conclusions

The research revealed significant improvement of ice navigation conditions within the eastern part of the Northern Sea Throughway (the routes “Sabetta Port – Vilkitski Strait – Bering Strait”) in September for the period of 1997-2018 years, especially within the Chukchee Sea. Nevertheless there is no full disappearance of the ice cover. Therefore there is necessity of ice cover parameters values determination for design of marine transport operations for long-term periods and operational supply of a marine transport operation. The design and supply demand usage of various computer models. The models are used for assessment of accident variability, ecological damage, choice of the optimal route at the operational supply. AARI has some skills of such models processing [11].

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